little or no rainfall during that year; and it was reported that the people had to resort to eating thistles, ground corncobs, and bark from trees. One writer who visited this region said that there was "not a leaf, a blade of grass, or a twig" in all four Provinces of northern China; for "a blade of grass no sooner made its appearance than it was pounced upon by a starving Chinese." Probably this is exaggerated.

It is true, however, that droughts of varying degrees of intensity occur at frequent intervals, especially in this northern sector. Serious crop failures and resulting famines are therefore just as frequent. The Government sometimes recognizes the seriousness of these by remitting all or a part of the taxes of the affected area. On the other hand, too much rain may come in too short a period and the people then must contend with floods. In fact, in this same region of north China, destructive floods occurred in 1917, only three years before the severe drought of 1920. Records show that the Chihli plain region may expect a flood once in six or seven years; this region is probably more subject to this sort of calamity because of the canal which connects Tientsin with a tributary of the Yellow River.

There are really three fundamental causes of floods here in northeastern China—first, erratic rainfall; second, deforestation; and third, the flat topography. In many places in this region the surfaces of the rivers are well above the general level of the plain and held in their courses only by natural or artificial dikes or levees.

In 1924 thousands of square miles of land were flooded. At one station in the district 23 inches of rain fell in 33 hours, and 9 inches of this came in 9 hours. This heavy downpour, coming as it did during the season when there was most rainfall, worked great havoc. Add to this the fact that water frequently remains on the land for months with the consequent drowning of any growing crops, and you have a measure of the destruction of property. The destruction is not confined to animals and crops; these floods also take their toll of human life. A definite and consistent national policy of reforestation and diking is the only adequate way of dealing with these floods, for rains will doubtless continue to be erratic. So far, only a little diking has been done, and almost no reforestation.

No treatment of the climate of China would be complete without some consideration of the typhoons, those violent tropical cyclones which so frequently ravage the southern coast. They loom large in Chinese history. Just as the Spanish Armada was destroyed by a violent cyclone in the English Channel, so a vast Chinese fleet of 3,500 ships assembled by the great Emperor Kublai Khan in the summer of 1281 for the invasion of Japan was totally destroyed by a typhoon. Of the 100,000 men who embarked on that fated expedition, only 3 returned. Perhaps the most violent storm of recent years was the so-called Swatow typhoon of August 1922, when 40,000 Chinese perished from the effects of the winds and water. As the center of the storm passed over the city the barometer fell to the unprecedentedly low level of 27.53 inches. The wind blew for two hours at an estimated rate of 100 miles an hour; and, as the center of the storm passed and the wind shifted from north to south, a great tidal wave inundated the city, drowning the closely packed Chinese inhabitants like rats. An interesting comparison might be made with the hurricane which visited Miami in September, 1926, when the barometer fell to 27.61, the lowest pressure ever recorded in the United States. Here, also, the wind blew at a speed of more than 100 miles an hour for two hours, first from the northeast and then from the southeast. From 8 to 16 inches of rain fell during the storm.

Unfortunately, China suffers from more frequent visitations by these tropical cyclones than does the United States. Chu found that during the 12-year period from 1904 to 1915, 54 typhoons struck the Chinese coast. Of these 54 all but 9 occurred in July, August, and September, and all but 3 entered the coast south of the twenty-eighth parallel. Thus, late summer is the most dangerous time, and southern China is the particular sufferer, for the typhoon loses much of its intensity as soon as it passes inland. Yet, once inland it may not die out; but, taking on the characteristics of an extratropical cylcone, it may pass northeastward over the interior and bring heavy rains to central and even to northern China. Most of the typhoons which visit China have their origin in the Pacific Ocean in the vicinity of the Caroline and Ladrone Islands.

M. A. GIBLETT ON LINE-SQUALLS [1]

"Squall" is defined as a sudden and violent gust, a blast or sharp storm of wind. The word "gust," it would seem, had been used earlier than "squall" and the implication is that it connoted a rise of wind of shorter duration than was implied by "squall." Some degree or precision was first given to these words as applied to wind when, after their intrusion into the vocabulary of the meteorologist, the pressure-tube anemometer was invented, an instrument that gives a continuous record of the wind and its fluctuations.

The "line-squall" is defined as a series of squalls occurring simultaneously along a line sometimes hundreds of miles long, advancing across the country at variable rates of speed. To such phenomena the word "line-squall" has been applied. The expression is synonymous with "wind-shift line" as used in the United States.

The characteristic manifestations of a line-squall on the ground are—

A sudden and rapid change of wind direction.
Heavy rain (or hail or snow).
Thunder and lightning.
A sunden fall of temperature.
A sudden or rapid rise of relative humidity.
A very rapid rise of barometric pressure during the passage.

The term "line-squall" is broadly applied to the ensemble of occurrences above listed.

The author considers the rapid fall of temperature as the basic characteristic of the phenomena and so treats the subject.

The fall of temperature is due to the arrival at the moment of a distinct colder mass of air which replaces the previously existing warmer current, and the line-squall is the physical result of this action. Accordingly, the basis of all that follows is the consideration of events when relatively cold masses of air impinge on relatively warmer ones. This brings into prominence the element temperature, which, at least from the point of view of airships, whether moored or in flight, is hardly second in importance to wind.

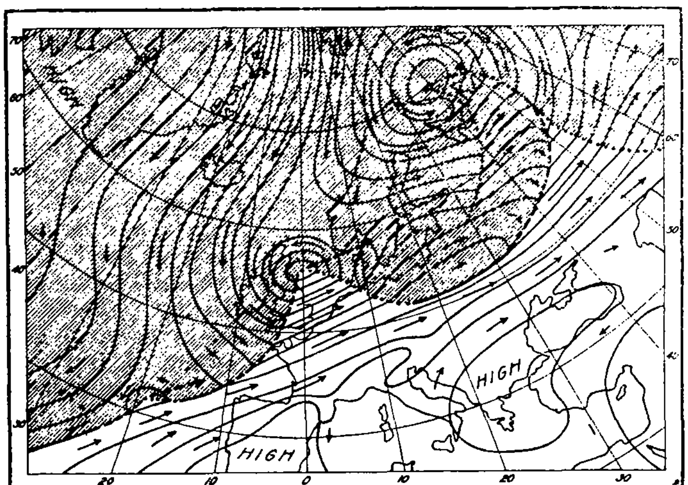
[1] Line-squalls, by M. A. Giblett, M. Sc. (Lond.). The Journal of the Royal Aeronautical Society, 198:509–549. June, 1927.

The author, who is superintendent airship meteorology division, Air Ministry, presents a very comprehensive discussion of line-squalls, from which the material here presented is abstracted.—*Editor.*

Line-squalls associated with barometric depressions of Temperate Zones.—In temperate regions, as is well known, the juxtaposition of relatively cold and warm air masses along lines of considerable length is found prinpally in association with the traveling low-pressure systems or barometric depressions of the middle latitudes; indeed, it is a fundamental feature of their structure.

The author uses as his illustrative material a typical distribution of barometric pressure over Europe and the northeast Atlantic Ocean during a disturbed period. It consists of a system of three depressions situated between anticyclones over the Mediterranean area and over the area southwest of Greenland. Analyzing this situation on modern lines, the author reveals a structure, the most important feature of which is shown on Figure 1.

Here the stippled area of the chart is that covered at the moment by air of direct, or rather, recent, polar origin, while the remainder of the chart is an area covered by relatively warmer air of recent tropical or subtropical origin. Arrows show the wind direction at about 1,500 feet at the time of the chart, the longer arrows indicating the stronger winds. It will be seen that the dividing



.... Warm Front
– – – – – Cold Front
--------- Secondary Cold Front
—·—·— Occlusion
———— Stationary Front

FIG. 1.—Illustrating the "polar front"

line along which the two air masses are in close contact is sinuous and that it is intimately connected with the depressions, forming a link between them which is not in any way apparent when Giblett's Figure 2 (not reproduced) alone is considered. This line has received the name "polar front" on the analogy of a battle front, because the warm and the cold air masses are in a state of conflict along it, the manifestation of this being the barometric depressions and associated air motion.

It is pointed out in the discussion of Figure 1 that the "polar front" is divided up into segments according to the key at the bottom of the figure. The middle one of the three depressions is seen to have a sector of warm air extending to its center. There is a law that the center moves in a direction parallel to the isobars of this warm sector, as shown in the figure by an arrow. During this displacement the forward boundary of the warm sector moves into the space at present occupied by cold air; in other words, along this segment of the polar front warm air is replacing cold, and the segment is called a "warm front." On the contrary, along the segment bounding the warm sector in the rear, cold air replaces warm, and this segment is called a "cold front."

The air of the warm sector, in addition to replacing the cold air at the ground along the warm front, actually gains on it and rises over it. The cold air which replaces the warm air at the ground along the cold front also gains on it and undercuts it. The result is that as time passes the cold front gains on the warm front and ultimately overtakes it. The combined cold and warm front is called an "occlusion," and an example is seen in the northernmost depression of Figure 1. The cold air in the rear of the occlusion is not necessarily at the same temperature as that in front, having had a different history; it is more frequently colder, in which case the occlusion retains some characteristics of the cold front, for we still have cold air replacing relatively warmer air.

The stage of occlusion is one of the later phases in the life history of depressions, and it has been reached in by far the greater number of depressions in the vicinity of the British Isles. The southern depression of Figure 1 has only recently formed, and its warm sector is as yet only a small wave in the polar front.

In addition to the segments of the polar front thus far described there are portions joining the cold front of one depression to the warm front of the next. These portions are temporarily stationary, neither warm nor cold air gaining along them. Further, "secondary cold fronts" may occur in the body of the polar air, as illustrated by the example attached to the northern depression in Figure 1. Here the polar air to the east is being replaced by yet colder polar air of somewhat different recent history.

The portions of the polar front in which primary interest is centered, as being those where line-squall phenomena manifest themselves, are the cold fronts, or segments where the polar air is gaining ground. Similar phenomena may be exhibited along occlusions and secondary cold fronts, but warm fronts are of a totally different character, and their detailed consideration is outside the scope of this paper. Cold fronts have also received the name "squall-line"; and in America "wind-shift line," what is often called the "trough" of a barometric depression, also coincides with the cold front.

The author believes the most logical view is to consider all cold fronts as line-squalls in the broader sense of a previous paragraph but to realize that the associated phenomena may be present with very different intensities in different cases. In what follows when the word "front" is used without qualification a cold front (or secondary cold front or occlusion) will be implied, but not a warm front.

MOTION OF LINE-SQUALLS; DIRECTION; SPEED; RELATION TO BAROMETRIC DEPRESSION

Certain definite questions about line-squalls may now be answered.

Figure 2 reproduces the polar front of Figure 1. The letters A, B, C, D, E, F, G, H, J, K, and M serve to indicate the position of the front at certain times; and the same letters with an accent, thus, A′, B′, C′, D′, etc., show the position six hours later; thus the depression centered at C having reached C′, that at F having reached F′, and that at K having moved very little to K′, slow movement being a characteristic of a depression when the occluded stage has been reached.

The idea once prevalent that line-squalls radiate from the centers of depressions like the spokes of a wheel is disposed of as follows: This is certainly approximately true of the cold front of a relatively young depression, such as that centered at F, but the cold front HJ does not bear such a relation to the occluded depression centered at K. Even if notice be taken of the occlusion JH, the whole HJK would form a very crooked spoke of a wheel with axis at K.

The question is asked, Is the advance of a squall line uniform along its whole length? And answered very definitely in the negative.

Figure 2 shows that in the case of the depression F the cold front near F has advanced almost across the North Sea in six hours, about 50 miles per hour, whereas the

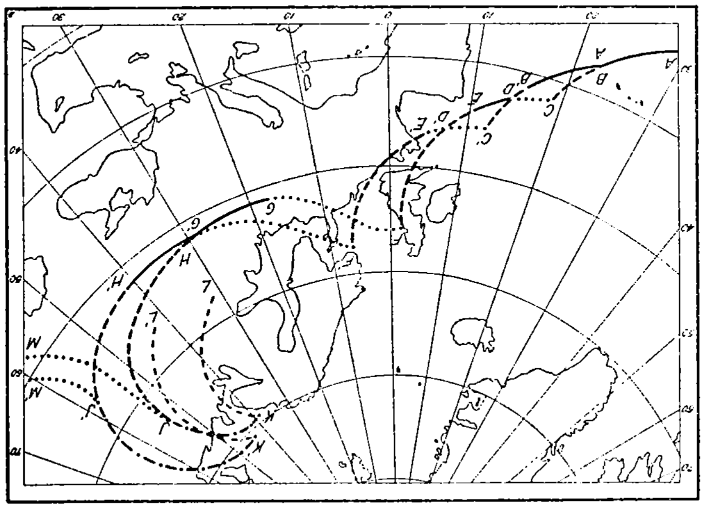


FIG. 2.—Illustrating the displacement of the "polar front"

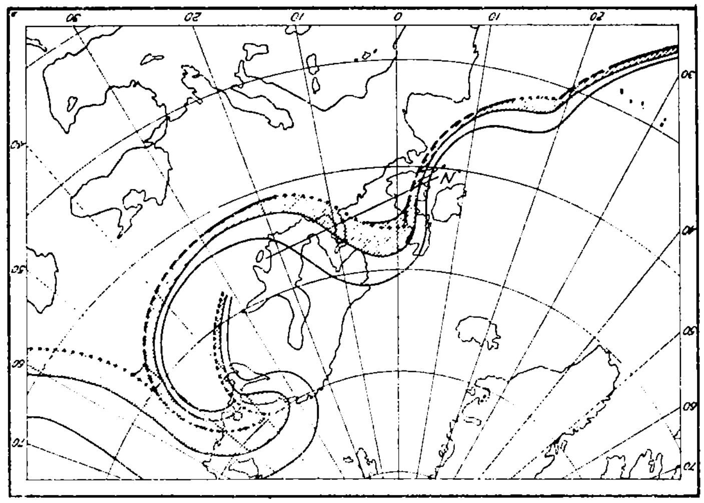


FIG. 3.—Illustrating the association of rain and cloud with the "polar front"

portion near Brest, having moved very little to D′E′, is then temporarily stationary prior to receding as the warm front C′D′ of the next depression. A rate of advance greater than 60 miles per hour may occur but is not common; rates of 30 miles per hour or more are quite common.

The question, Is there any relation between the rate of advance of a line-squall and that of the depression with which it is associated? is asked, and answered by the statement that there is no simple relation. There is, however, one simple relationship of practical value when using weather charts, and that is that in active systems the rate of advance of any section of a cold front is approximately equal to the component perpendicular to the front of the gradient wind in the polar air in its rear (the gradient wind being the theoretical wind at 1,500 feet as readily measured from isobars on the chart).

The direction of motion of line-squalls is said to be normally from somewhere between northwest and southwest or south to north. There is very rarely a component from the east in the motion.

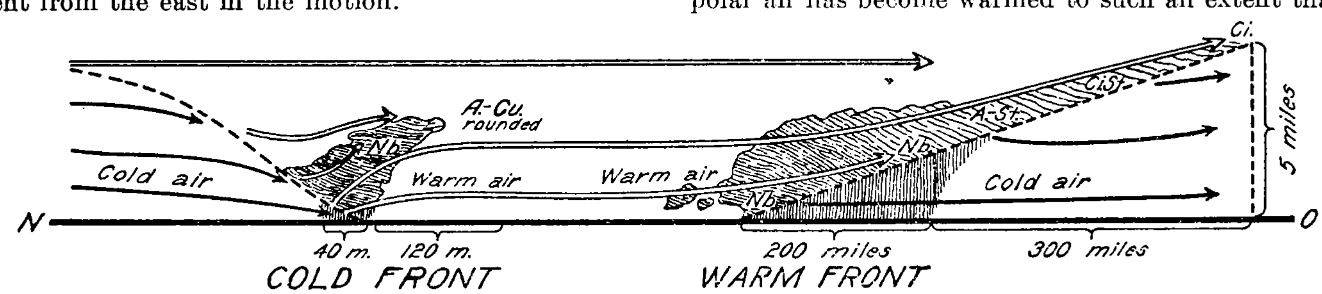


FIG. 4.—Section along N—O of Figure 3

FREQUENCY OF OCCURRENCE OF LINE-SQUALLS; HORIZONTAL LENGTH; LENGTH OF LIFE

Since there are cold fronts associated with all active depressions of temperate latitudes the frequency of line-squalls, including all degrees of intensity, is high, but for every severe one there are many of only moderate or slight intensity. Line-squalls may recur at any place at short intervals during some periods, and then there may be a period of even weeks free from them.

The horizontal length of a line-squall in a characteristic case is well represented by those of the cold fronts in Figure 2, i. e., anything up to a thousand miles. And we have already seen that there is a considerable variation of speed of advance along the front.

The length of life of a line-squall is often at least 24 hours, but in this connection is is necessary to consider its transition. The length of life may be very different for various portions of the same front. In Figure 2 the northern portion of the cold front EF will ultimately overhaul the warm front FG and form an occlusion. It may be many hours before this is achieved, and even afterwards the occlusion may have the character of a cold front and persist for a further considerable period before dying out. The southern portion of EF is, on the contrary, slowing down, shortly to become stationary at D′ E′ and then to become in turn a portion of the warm front C′ D′ of the next depression. The length of life of the polar front of Figure 2, considered as a whole, is much longer than the period during which any one portion of it retains a particular form, as old depressions die and new ones form in association with it, until ultimately the polar air has spread over the whole area at present occupied by the warm air, or until the polar air has become warmed to such an extent that the contrast of temperature disappears. This marks the end of that particular spell of disturbed weather.

Figure 3 is another presentation of the polar front of Figure 1 in which the stippled area represents, necessarily in a somewhat idealized way, the associated rain

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area. Any rain falling elsewhere would be purely local. The continuous line outside the rain area represents the outer edge of the cloud system responsible for the rain.

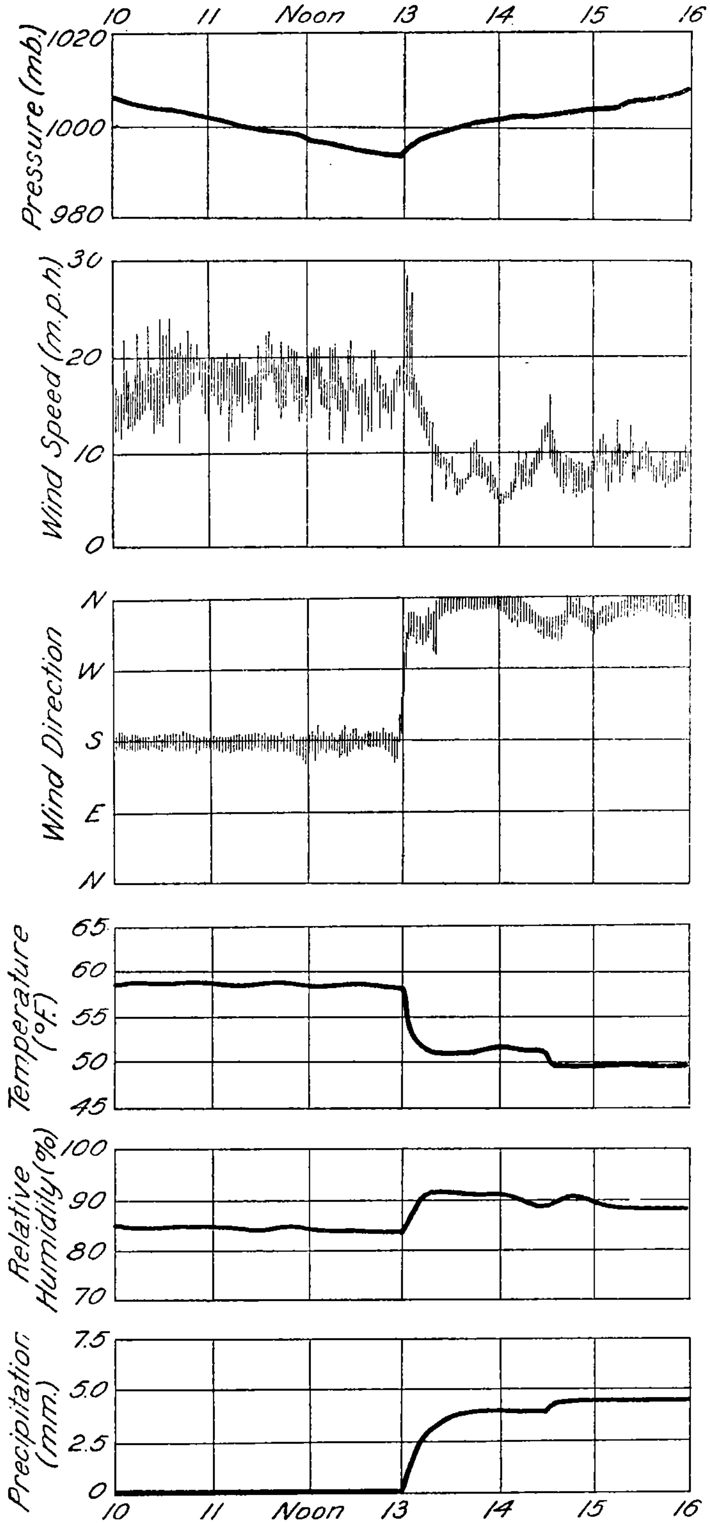

FIG. 5.—Changes during the passage of a typical cold front

Figure 4 shows the vertical sections along the line N—O of Figure 3 and gives a generalized view of conditions in the upper air. This diagram should be read in connection with Figure 3.

Events at a ground station during the passage of a cold front.—In general the sequence of changes in the several weather elements are shown in Figure 5 and little comment is necessary.

The barometric pressure which has been falling steadily shows a rapid rise at the time of incidence of the cold front, followed by a more gradual rise. The magnitude of the rapid rise is often several millibars in a few minutes. The wind speed shows a sudden increase of short duration, followed by a decline to a less value than before the squall.

This is typical, but important modifications may sometimes occur. At the time of the squall the wind direction shows a rapid change from south to northwest. The change is often complete in less than a minute, but, though always in the same sense in the northern hemisphere, is often through a much smaller angle. A fall of 10° F. in a few minutes is not uncommon. The characteristic rainfall is an intense shower (sometimes of hail) at the time of incidence of the squall, often accompanied by thunder, and followed by a short period of less heavy rain, often only half an hour. (The rainfall curve in fig. 5 is such that the height of any point above the base line represents the total fall up to that time, so that when no rain is falling the curve is horizontal.)

Events in the upper air during the passage of cold front.—In the upper air the passage is marked by dense cloud masses and violent vertical currents. Reference to Figure 4 shows that in consequence of the backward slope of the boundary between warm and cold air (the whole system being supposed moving from left to right) the arrival of the cold air, and with it the shift of the wind, is delayed the more the higher the level considered. The first 1,000 feet or so are, however, excepted for reasons to be explained. The total fall of temperature at, say, 10,000 feet is often much greater than at the surface. Soundings by airplane in the British Isles, before and after the passage of cold frosts, have shown falls of 20° F., when those at the surface have been only a few degrees. The precise rate of fall and rapidity of wind shift at higher levels have not been directly measured, but they probably do not often take place in such a very short time as at the surface.

DETAILED STRUCTURE OF LINE-SQUALL

Considering now in much more detail conditions a few miles on either side of the line-squall, or forward edge of the cold air in the cold front of Figure 4, the horizontal distance is only just distinguishable on the scale of that diagram. Owing to the difficulty of observing, no complete survey of any one case at all heights has ever been made, but there are many fragmentary observations available of various phases of different cases. Piecing these together and combining with them personal observations and certain theoretical considerations, the author arrives at a picture of the essential features in the immediate neighborhood of the line-squall, and this is shown in Figure 6.

In this diagram the horizontal and vertical scales are the same, so that a correct idea of the proportions is at once given. The shaded area is a section through the tip of the cold wedge which is supposed to be advancing to the right.

Owing to surface friction the cold air is found farther advanced some distance above the surface than at the ground itself, and the upper limit of the cold air AB, instead of continuing on until it cuts the ground, is doubled back and meets it at the point C. This point is to be considered as marking the cold front at the ground. The rate of advance of this point to the right in the diagram, or in other words the speed of the cold air at C in this direction, is the rate of advance of the front. In a typical case, the passage of the whole portion of the cold wedge shown in this diagram would only be a matter of 10 minutes or so. Beyond the left of the diagram the upper boundary of the cold air slopes at a smaller angle still and the rise in pressure consequently proceeds less rapidly.

The various arrows indicate the main features of the air motion in the plane of the diagram, *relative* to the point C—i. e., as they would appear to an observer traveling along C (the velocity of C is to be added at all points to obtain the actual motion). The arrow at D means that the air there is being overtaken by the cold wedge. When the air arrives at E it immediately comes under the influence of the strong pressure gradient and its passage of C, when a decrease of wind takes place. The arrow at H indicates that the air there is losing on the front C.

As regards vertical motion, the strong horizontal convergence between D and E necessitates a strong upward current at F. If there is sufficient water vapor present, cloud will form here; and owing to the tendency of the cold air at B to fall, a rolling motion, as indicated, may be imparted to this cloud, which is the characteristic long roll cloud of a line-squall seen in cross section.

On the other hand, the divergence between C and H necessitates a downward current at G. This is in general quite gentle, being spread over a wide area and not concentrated like the upward current at F.

The warm air, having risen over the front edge of the cold wedge, is farther lifted above the upward sloping boundary AB; and, if moist enough, a cloud sheet will form as at N and from this rain may fall through the cold air beneath. The whole system as so far described represents the phase of development of the Aberdeen

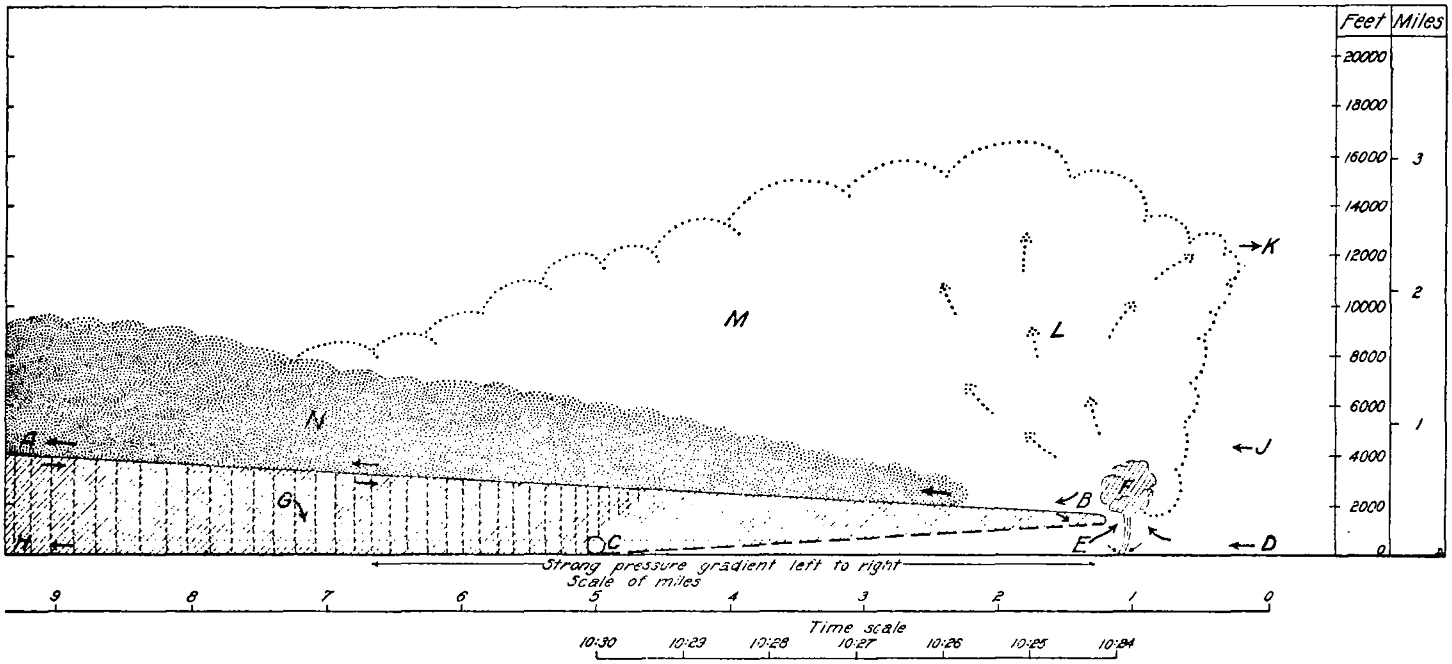

FIG. 6.—Detailed structure of line-squall

relative motion is checked or even reversed. It is therefore on the passage of this point that the first sudden change of wind takes place at a ground station.

The squall as measured on an anemogram may be said to have commenced. It continues until a little after the line-squall of October 14, 1912, of which a detailed description accompanied by cloud sketches has been given by Mr. A. G. Clark in his book on "Clouds."—*A. J. H.*

HORTON AND GRUNSKY ON THE HYDROLOGY OF THE GREAT LAKES [1]

Abstracted by ALFRED J. HENRY

This volume of 432 octavo pages is replete with hydrologic and related data bearing upon the rise and the fall of the level of the Great Lakes due to natural causes or as the authors put it—the cycle rainfall, run-off, and evaporation. This cycle as related to the Great Lakes invloves the following-named elements:

(1) Rainfall on the drainage basins tributary to the Lakes.
(2) Rainfall on the lake surfaces.
(3) Evaporation from the lake surfaces.
(4) Run-off and inflow into the Lakes.
(5) Outflow from the Lakes.
(6) Lake levels and their fluctuations.

Measurements.—More or less isolated measurements of outflow were made from time to time but it was not until about 1896 that systematic measurements were undertaken by the U. S. Lake Survey. Complete records of lake levels extend back to 1860, and approximate levels can be carried back to 1835. Records of precipitation

[1] Report of the Engineering Board of Review of the Sanitary District of Chicago on the Lowering Controversy and a Program of Remedial Measures, Part III, Appendix II, by Robert E. Horton, in collaboration with C. E. Grunsky, 1927.